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(71) Applicants:
• SCRIMP SYSTEMS, L.L.C.
Warren, RI 02885 (US)
• Hardcore Du Pont Composites, L.L.C.
New Castle, DE 19720 (US)

(72) Inventors:
• Tunis, George C., III
Wilmington, DE 19808 (US)

• Haraldsson, Rikard K.
Elkton, MD 21921 (US)
• Seemann, William H., III
Pass Christian, MS 39571 (US)
• Everitt, William E.
Hockessin, DE 19707 (US)
• Perrella, Andrew P.
Hockessin, DE 19707 (US)
• Pearson, Everett A.
Warren, RI 02885 (US)

(74) Representative: Prins, Adrianus Willem et al
Vereenigde,
Nieuwe Parklaan 97
2587 BN Den Haag (NL)

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divisional application to the application mentioned
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(54) Production of large composite structures

(57) Large composite structures are produced using
a vacuum assisted resin transfer molding process incor-
porating a resin distribution network. The resin distribu-
tion network is provided by a textured sheet (104) of
metal formed as an integral vacuum bag and mold. The
texture is formed by upraised portions (108) on one side
of the sheet which correspond with depressions on the

other side. Valleys between the upraised portions form
the resin distribution network. A fiber lay up is placed
against the textured sheet (104) with the upraised por-
tions facing the lay up. Main feeder grooves (114) are
also formed directly in the sheet (104). Resin is supplied
under vacuum to the main feeder grooves, from where
it travels through the valleys of the textured sheet (104)
to impregnate the lay up.

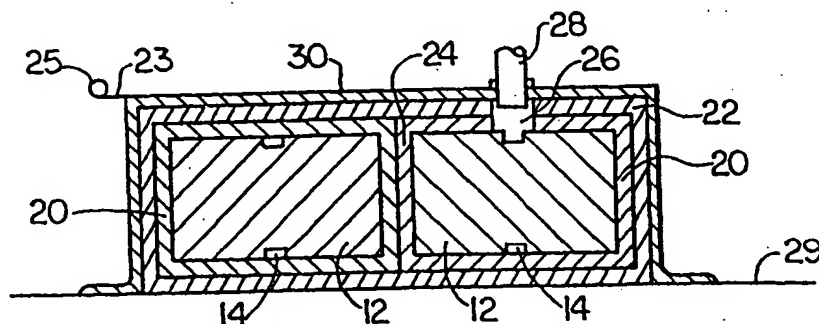


FIG. 2

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Description

FIELD OF THE INVENTION

[0001] This is a divisional application of EP-A 96921312.3, the contents of which are incorporated into this application by reference.

[0002] This invention relates to the production of fiber-reinforced resin composite structures, and in particular to processes for vacuum assisted resin transfer molding of large composite structures.

BACKGROUND OF THE INVENTION

[0003] Vacuum assisted resin transfer molding (VA-RTM) has been used to produce a number of large, fiber reinforced composite structures such as boat hulls which incorporate materials such as foam and balsa cores. The cores are covered with a fiber reinforced resin. In the VA-RTM process, the reinforcement fiber, such as a fabric or mat, is arranged in a single sided mold in a dry condition along with the desired core materials according to the form of the desired finished part. The lay-up is then encapsulated in a vacuum bag and impregnated with resin under vacuum. The resin is allowed to cure.

[0004] Various methods have been utilized to introduce and enhance the distribution of resin through the reinforcement fiber. These methods include the placement of a disposable distribution media over the outside layer of fabric and the incorporation of holes and/or slots penetrating through the core to allow resin to flow from the outer to the inner layer of reinforcement fiber. See, for example, U.S. Patent Nos. 5,316,462 and 4,560,523. A supply groove in a foam core has also been used in a closed mold resin injection process to facilitate resin flow. See, for example, U.S. Patent No. 5,109,651.

SUMMARY OF THE INVENTION

[0005] The present invention relates to a method for distributing resin during the manufacture of large composite structures using a vacuum assisted resin transfer molding (VA-RTM) process and the composite structure produced by this method. The composite structure is formed from internal cores surrounded by fiber reinforced resin. In one embodiment of the invention, resin is supplied directly into a network of main feeder grooves which are interconnected to a series of smaller microgrooves formed in the surface of the internal cores. From the feeder grooves and microgrooves, the resin flows outwardly from the core to penetrate the reinforcement fiber. In a second embodiment of the invention, a separate distribution medium is interposed between the internal core and the fiber reinforcement. The resin is supplied directly to one or more main feeder grooves in the core surface and penetrates the reinforcement fiber via the distribution medium. Also, the main feeder

grooves can extend around the cores to form supply loops, allowing impregnation of transverse structural members.

[0006] In a further embodiment, an integrated vacuum bag and mold are formed from a textured sheet of metal. The texture is formed by closely spaced upraised portions on one side of the sheet which correspond with depressions on the other side of the sheet. The closely spaced upraised portions define valleys therebetween which form a resin distribution network. Main feeder grooves are formed directly in the sheet. The textured sheet can also be used as a mold from which other tools are made.

[0007] With this method, large composite structures which require multiple cores can be formed quickly prior to the gel time of typical vinyl ester or polyester resins, and the amount of resin used can be minimized. By supplying the resin directly through the vacuum bag into the feeder grooves, the supply is not limited to a part edge or inlet in a tool. Adjacent cores can be supplied via a single resin inlet. The resin distribution network can remain in the finished part, eliminating disposal of distribution materials. In this case, the microgrooves are filled with resin after curing, thereby increasing interlaminar shear strength and delamination strength. Structural features such as shear ties, compression webs, or beams can be incorporated directly into the composite part during the molding process.

DESCRIPTION OF THE DRAWINGS

[0008] The invention will be more fully understood from the following detailed description taken in conjunction with the accompanying drawings in which:

Fig. 1 is a perspective view of a core for a composite structure according to a first embodiment of the present invention;

Fig. 2 is a schematic cross-sectional view of a composite structure being formed according to the first embodiment of the present invention;

Fig. 3 is a schematic perspective view of a further composite structure being formed according to the present invention;

Fig. 4 is a perspective view of a composite structure being formed according to the present invention;

Fig. 5 is a perspective view of a further core for a composite structure according to the present invention;

Fig. 6 is a perspective view of a core for a composite structure according to a second embodiment of the present invention;

Fig. 7 is a schematic cross-sectional view of a composite structure being formed according to the second embodiment of the present invention;

Fig. 8 is a schematic cross-sectional view of a composite structure being formed using an integrated mold and vacuum structure;

Fig. 9 is a schematic cross-sectional view of a rigid mold and flexible lid for forming a composite structure;

Fig. 10 is a perspective view of a core for a composite structure having multiple main feeder grooves;

Fig. 11 is a schematic cross-sectional view of an integrated mold and vacuum bag for forming a composite structure according to a further embodiment of the present invention;

Fig. 12 is a perspective view of one side of a textured sheet of material forming the integrated mold and vacuum bag of Fig. 11; and

Fig. 13 is a perspective view of the other side of the textured sheet of Fig. 12.

DETAILED DESCRIPTION OF THE INVENTION

[0009] A large composite part made according to the present invention includes a core 12, shown in Fig. 1. The core is made from a material able to support the pressure of a vacuum. Typical materials include foams, such as a polyurethane or a polyvinyl chloride, or balsa wood. The core can be solid or hollow, such as a blown polyethylene. Concrete may also be used. The core is shown as a rectangular block, although other configurations are possible, as discussed further below.

[0010] One or more main feeder grooves or channels 14 are provided in the surface 16 of the core. The main feeder groove may circumscribe the entire core to form a loop. A resin distribution network comprising channels of a smaller cross-sectional area than the main feeder groove is provided in contact with the surface of the core for fluid communication with the main feeder groove.

[0011] In a first embodiment of the present invention, the resin distribution network is provided in the form of a plurality of microgrooves 18 machined in the surface 16 of the core 12, as shown in Fig. 1. The microgrooves 18 are generally arranged transversely to the main feeder groove 14. Some of the microgrooves may circumscribe the entire core to create a resin flow loop beginning and ending at the main feeder groove. The actual relation of the microgrooves to the main feeder groove depends on the geometry of the core and the optimization of the resin impregnation, as discussed further below.

[0012] The core 14 with the network of grooves is covered with one or more layers of a fiber material 20, illustrated schematically in Fig. 2. The fiber material may be a cloth or mat formed from fibers of glass, carbon, or other suitable material. Depending on the structural requirements of the desired finished part, the core may be completely surrounded with fiber material, or one or more surfaces of the core may be left free of fiber material. The fiber material may be wrapped in a sheet around the core, or individual pieces of fiber material may be applied to the desired core faces. The fiber may also be supplied in a tubular form into which the core is

inserted.

[0013] A plurality of fiber wrapped cores are arranged to form the desired finished part. Although two cores are shown in Fig. 2, the actual number and arrangement of cores is determined by the desired finished part. One or more layers of a fiber material can be wrapped around a plurality of cores to form an outer skin 22, shown schematically in Fig. 2. The particular number of layers of fiber material, the type, and the arrangement depend on the desired finished part and can be readily determined by those of skill in the art. A bleeder layer is generally provided in the form of a tab 23 extending from an outer fiber layer to a vacuum outlet 25. Peel plies, typically required with prior art vacuum processes, are generally not needed with the process of the present invention.

[0014] The fiber material 24 surrounding and between the cores creates structural members such as shear ties, compression webs, and beams. For example, referring to Fig. 4, a plurality of triangular cores 40 are used to form a deck. The fiber material between adjacent triangular cores forms diagonal structural members 41 that support both compression and shear forces.

[0015] During the lay-up, suitable fittings 26, such as plastic or copper tees, are positioned in the main feeder grooves 14 to facilitate the subsequent insertion of resin supply tubes 28. One or more fittings may be positioned in each feeder groove, to accommodate the desired resin flow. The lay-up is placed against a mold 29, and a vacuum bag 30 is then placed over the lay-up, including the plastic fittings, and sealed to the mold in a manner known in the art, as shown schematically in Fig. 2. The vacuum bag is then punctured and the supply tubes 28 are inserted through the vacuum bag directly into their respective fittings 26. The supply tubes are sealed to the bag to retain vacuum integrity. In this manner, the main feeder grooves are supplied directly with resin by penetrating the outer vacuum bag with a supply tube that is inserted directly into the groove.

[0016] Referring to Fig. 8, the vacuum bag and mold may also be integrated into a single structure 80 which is rigid enough to retain its shape as a mold but flexible enough to collapse against the part upon application of a vacuum. For example, the integrated structure 80 may comprise a thin gauge steel sheet, such as 0.25 inch or thinner. The cores 82 and fiber material 84, 86, as described above, are encapsulated in the steel sheet. Holes are drilled through the sheet to access the fittings. Resin impregnation occurs as described above. The integrated structure may be formed of other suitable materials, such as rubber or silicone or a thin composite sheet material such as a plastic laminated metal.

[0017] Fig. 9 illustrates a further mold embodiment in which a rigid mold 90 is sealed with a flexible lid 92 formed, for example, from a steel or plastic material. A part, comprising the cores and fiber material as described above, is placed in the recess 94 defined by the rigid mold. A vacuum groove 96 in the lid surrounds the part. Holes are provided through the lid or mold to ac-

cess fittings for resin impregnation as described above. During impregnation of the resin under vacuum, the lid flexes at the edge of the vacuum groove, to allow compaction of the part.

[0018] The resin, such as a polyester, vinyl ester, epoxy, phenolic, acrylic, or bismaleimide, travels relatively quickly through the main feeder grooves 14 and into the microgrooves 18. From the microgrooves, the resin penetrates the fiber material 20, 22. Impregnation results from resin infusion originating at the core surface 16 and migrating outwardly to the exterior of the part. The fiber material on adjacent core surfaces may be impregnated via a main feeder groove in one of the adjacent cores, as indicated in Figs. 3 and 4.

[0019] The cross-sectional area of the main feeder groove and the cross-sectional area and spacing of the microgrooves are optimized to provide a suitable time to allow the resin to impregnate all of the fiber material before curing without leaving unimpregnated areas. A typical main feeder groove may have a depth of 0.5 inch and a width of 0.5 inch for a cross-sectional area of 0.25 square inches. Typical microgrooves may have a depth of 0.125 inch and a width of 0.125 inch for a cross-sectional area of approximately 0.016 square inches. The microgrooves may be spaced 1.0 inch on center. These dimensions may be modified to accommodate reinforcement fiber materials of different types and/or thicknesses. Also, the cross-sectional area of the main feeder grooves may be increased if the part is particularly large to more rapidly distribute the resin to all sections of the part. Similarly, multiple main feeder grooves 14 may be provided in a core 12, as indicated in Fig. 10.

[0020] In addition, the cross-sectional area of the main feeder grooves or the microgrooves may be reduced to create flow restrictions to increase resin dwell time at a particular area. Resin dwell time may also be increased by placing a resin "fuse" in the feeder groove which temporarily blocks the resin flow. The fuse dissolves after contact with the resin after a known period of time, which may be set by the length of the fuse. For example, with a vinyl ester resin, a styrofoam fuse has been used successfully. The feeder grooves may also terminate to redirect resin flow.

[0021] The main feeder grooves 14 allow passage of resin from one core to an adjacent core. Holes may be provided through the cores to connect main feeder grooves. Each main feeder groove may be supplied with resin simultaneously, creating parallel circuits, or in a prescribed sequence, creating series circuits, depending on the geometry and size of the part to be impregnated. Additionally, the main feeder grooves may be independent of each other, creating separate circuits.

[0022] After impregnation, the resin is allowed sufficient time to cure. Once cured, the microgrooves 18 are filled with solid resin. This resin provides a lateral locking mechanism which improves the interlaminar shear strength of the bond between the fiber reinforced composite and the core. The resin remaining in the groove

network also increases the forces necessary to delaminate the fiber reinforced face skins from the core.

[0023] The actual arrangement and shape and number of cores depends on the desired finished part. For example, triangular cores 40 are shown in Fig. 3. The triangular cores may have main feeder grooves 42 provided in at least two surfaces. A central triangular core 44 may have main feeder grooves in three surfaces. Microgrooves are provided in the surfaces as described above. A plurality of triangular cores may be arranged in, for example, a row to form a deck. In this example, resin, supplied through tubes 46, is impregnated sequentially beginning at the central core and progressing toward the edges, as shown by the shaded region 48 in Fig. 4.

[0024] An arcuate core 50 is shown in Fig. 5. The arcuate core 50 may have a main feeder groove 52 in one surface and a network of microgrooves 54 radiating from the feeder groove to circumscribe the core. The arcuate cores may be used to form curved structures such as boat hulls or arches.

[0025] In another embodiment of the present invention, illustrated in Figs. 6 and 7, a core 60 is provided with a main feeder groove 62 as described above. A distribution medium 64 is then provided adjacent the core faces. The medium comprises a network of open passageways formed by a structure capable of maintaining the passageways in an open condition during application of the vacuum. For example, the medium may comprise intersecting filaments held in spaced relation from the core surface by post-like members located at each filament intersection, a grid-like structure of aligned strips, or an open weave fabric. Suitable distribution media are known for example, from U.S. Patents Nos. 4,902,215 and 5,052,906, incorporated herein by reference. A fiber material 66 is then wrapped over the distribution media, as described above. A plurality of cores are arranged to form the desired finished part, and a vacuum bag 68 is placed over the cores and fiber material, as described above. Resin supply tubes 70 leading from a resin source are inserted through the bag 68 and fiber material 66 to fittings 72 in the main feeder grooves 62. The supply tubes 70 are sealed to the vacuum bag in a manner known in the art. Resin is fed through the supply tubes to the main feeder grooves. The resin travels relatively quickly through the main feeder grooves and into the distribution media. From the distribution media, the resin penetrates the fiber material. A suitable time interval is provided to allow the resin to cure.

[0026] Resin distribution media presents a more uniform resin flow front than the microgrooves. For this reason, resin distribution media are generally preferred for more complicated parts, whereas microgrooves are preferred to conserve resin, since less resin flows through the microgrooves. In a further embodiment, illustrated in Figs. 11 through 13, the vacuum bag and mold are integrated into a single tool 102 formed from a textured

sheet 104 of metal, such as a thin gauge steel sheet. The sheet is rigid enough to retain its shape as a mold, but flexible enough to collapse or be pulled against the part under the vacuum applied during a resin impregnation process, discussed further below. A sheet thickness of 0.25 inch or less has been found suitable. A plastic or a composite material such as a metal and plastic laminate formed as a textured sheet may also be used.

[0027] Preferably, the texture is formed by closely spaced upraised portions 108 formed on one side of the sheet 104 which correspond to depressions 106 on the other side of the sheet. The closely spaced upraised portions 108 define valleys 110 therebetween which form a resin distribution network. For example, the upraised portions may have a generally hexagonal shape having a longest dimension of between 3/8 inch and 7/16 inch. A depth of the valleys of approximately 30 thousandths of an inch has been found to be suitable. Such a textured sheet is readily formable and is commercially available from Ardmore Textured Metal of Edison, New Jersey. Alternatively, the texture could be provided on a single side of the sheet if desired, such that the upraised portions do not make corresponding depressions on the other side.

[0028] The sheet is shaped into the desired form of a mold 112 having a mold cavity 118 with the upraised portions of the sheet forming the interior walls of the cavity, thereby facing the part to be impregnated. Main feeder grooves 114 are formed directly in the sheet 104 in the desired locations, rather than in the cores as described above. The main feeder grooves may have dimensions as discussed above. Vacuum outlet channels 116 are formed around the perimeter of the tool.

[0029] To form a composite part, a fiber lay up is placed within the cavity 118 adjacent the textured surfaces of the tool, and the tool is sealed as with a tacky tape or other seal as is known in the art. A peel ply may be used if the texture is not to be retained on the part. Alternatively, a peel ply may be omitted if the texture is desired to be retained on the surface of the part. Forming the texture on the part imparts some further stiffness to the part and may be desired for esthetic reasons as well. The fiber lay up may comprise cores wrapped with fiber material as discussed above. Fittings are inserted into the main feeder grooves through punctures made in the sheet as discussed above. A vacuum is applied to the interior of the tool, and the sheet of textured material is pulled adjacent the fiber lay up such that the tops of the upraised portion contact the fiber lay up, but the valleys remain open to form a network of narrow, interconnected passageways through which resin is able to flow. Under the vacuum, resin is drawn first into the main feeder grooves and then into the valleys. From the valleys, the resin is able to fully impregnate the fiber material, flowing finally to the vacuum outlet channels around the perimeter. The resin is allowed sufficient time to cure. After curing, the part is removed from the tool.

[0030] In an alternative embodiment, the textured

sheet can be used as a lid in conjunction with a conventional mold. The fiber lay up is placed against the mold surface. The textured sheet is placed over the fiber lay up and sealed to the mold in any suitable manner. Additional resin distribution media may need to be used adjacent the conventional mold surfaces. Resin impregnation occurs as discussed above.

[0031] The textured sheet can also be used as a master mold which is used to make tools from other materials, such as ceramics. The tool is then used as a mold in the resin impregnation process. In this case, the sheet comprises a negative of the tool; that is, the side of the sheet having the indentations is used to form the tool. The resulting tool has the configuration of the upraised portions separated by the valleys, which form a resin distribution medium as discussed above. A ceramic mold generally does not flex to collapse against the part under vacuum. In this case, a separate vacuum bag is used in conjunction with the mold, as is known in the art.

[0032] The invention is not to be limited by what has been particularly shown and described, except as indicated by the appended claims.

25 Claims

1. A unitary composite structure comprising:

a core having a peripheral surface and a feeder channel formed to lie across at least a portion of said peripheral surface of said core;
a resin distribution network adjacent said core peripheral surface and said feeder channel in said core peripheral surface;
a fiber material covering said core, said feeder channel, and said resin distribution network;
and
a cured resin impregnating said fiber material, said feeder channel, and said resin distribution network.

2. The structure of claim 1, wherein said resin distribution network comprises a network of grooves formed in said surface of said core extending from said feeder channel, said grooves having a smaller cross-sectional area than said feeder channel,

3. The structure of claim 1 or 2, wherein said grooves are arranged transversely to said feeder channel,

4. The structure of claims 1-3, wherein at least a portion of said grooves circumscribe said core to form a loop beginning and terminating at said feeder channel.

5. The structure of claim 1, wherein said resin distribution network comprises a resin distribution medium laid adjacent to said peripheral surface of said

core.

6. The structure of claim 5, wherein said resin distribution medium comprises intersecting filaments held in spaced relation from the core surface by post-like members located at each filament intersection, a grid-like structure of aligned strips, or an open weave fabric. 5
7. The structure of claim 1, further comprising a plurality of said cores, each having a peripheral surface and a feeder channel formed in said surface extending throughout a length of said core, and arranging said cores adjacent to each other. 10
8. The structure of claim 7, wherein said cores are arranged adjacent to each other with each of said feeder channels generally aligned. 15
9. The structure of claim 1, wherein said core comprises a foam material. 20
10. The structure of claim 1, wherein said core comprises balsa wood. 25
11. The structure of claim 1, wherein said core comprises concrete. 30
12. The structure of claim 1, wherein said core comprises a block having a generally rectangular cross-section. 35
13. The structure of claim 1, wherein said core comprises a block having a generally triangular cross-section. 40
14. The structure of claim 1, wherein said core comprises a block having an arcuate face. 45

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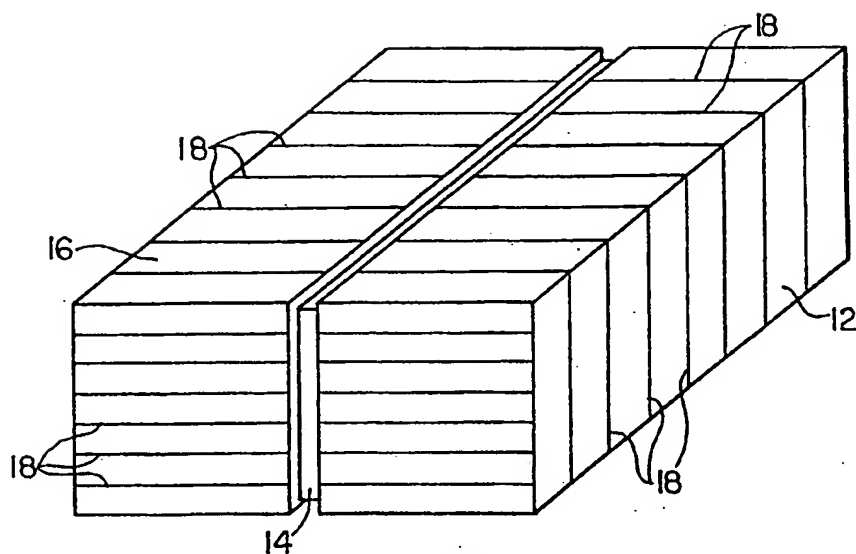


FIG. 1

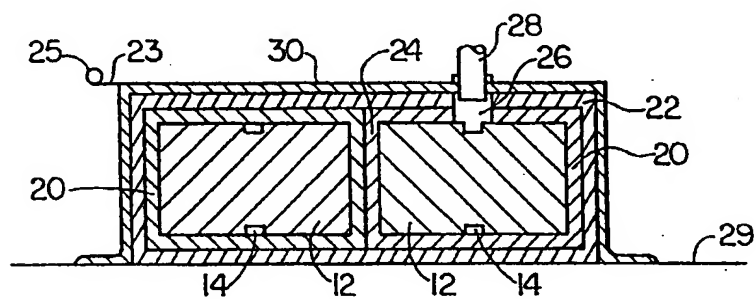


FIG. 2

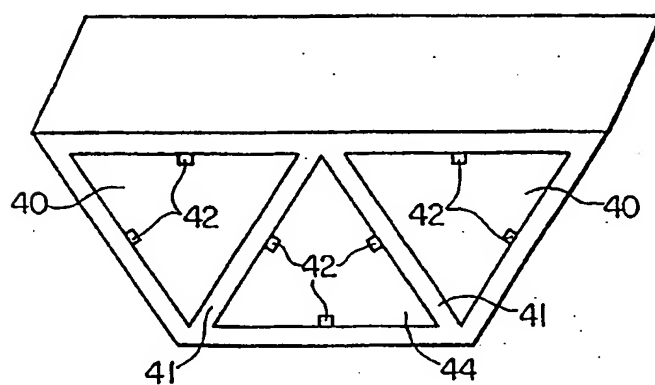


FIG. 3

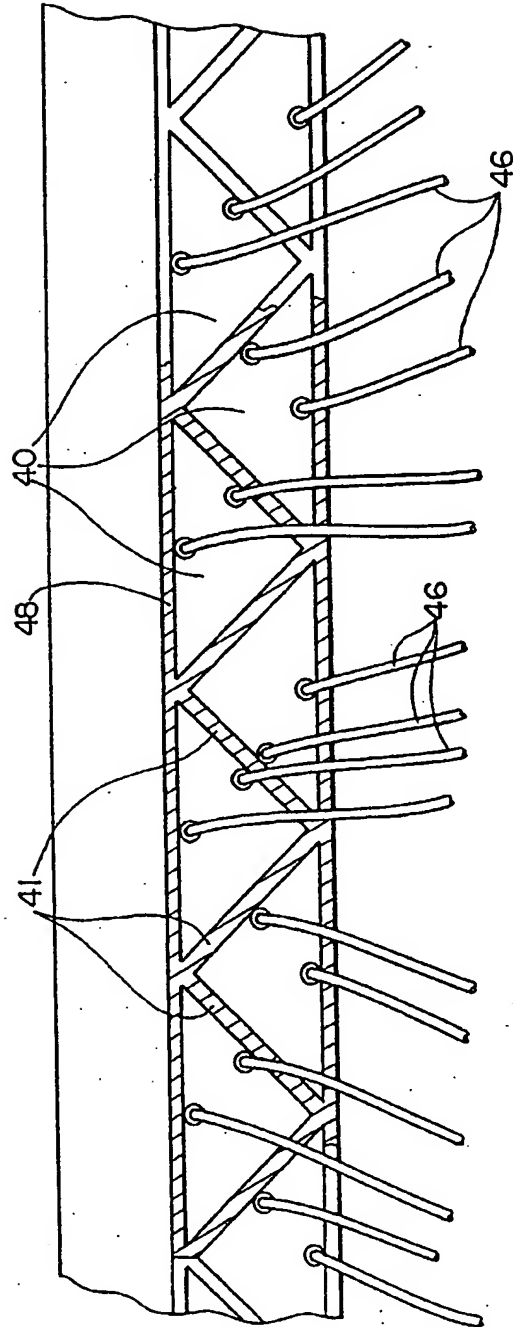


FIG. 4

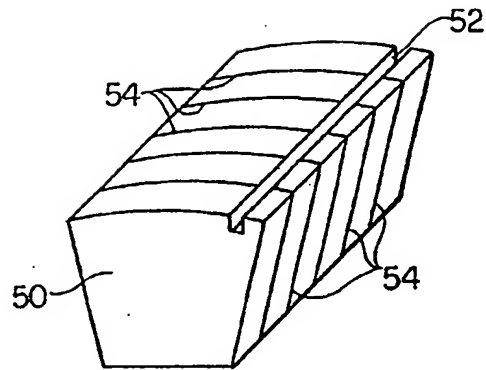


FIG. 5

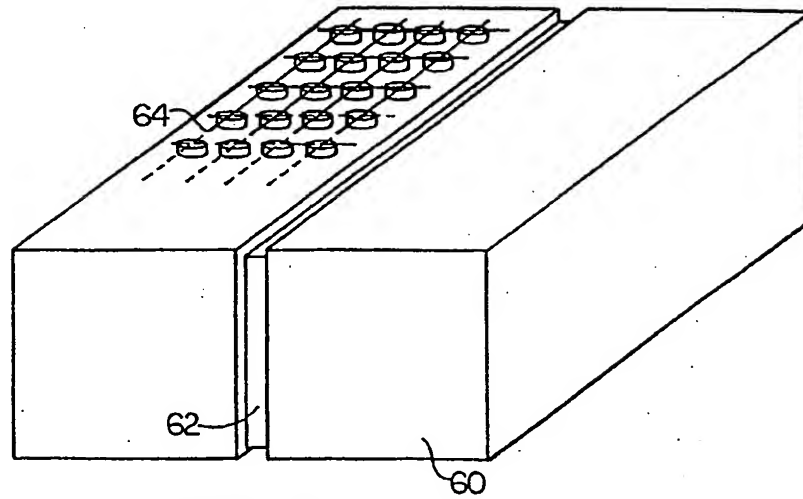


FIG. 6

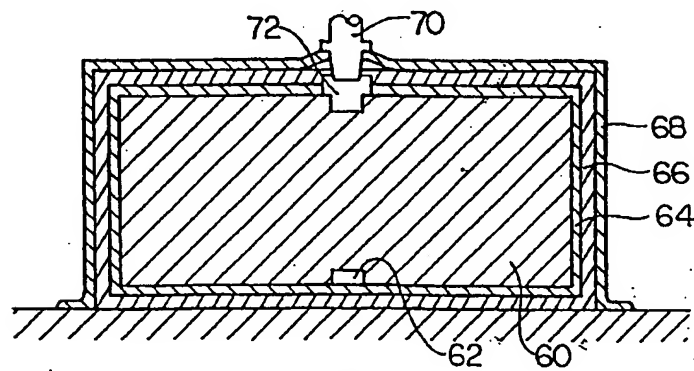


FIG. 7

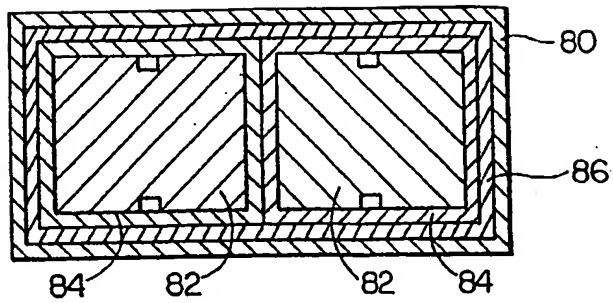


FIG. 8

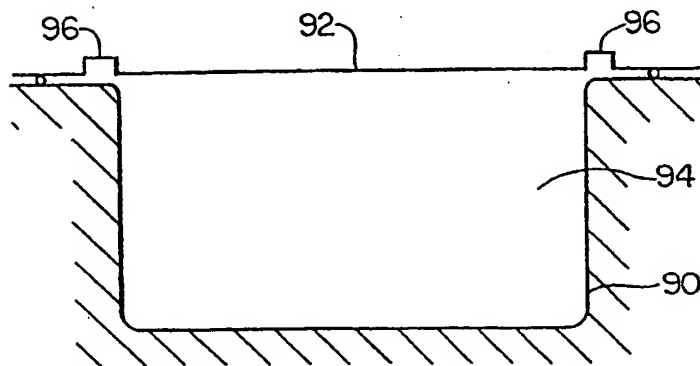


FIG. 9

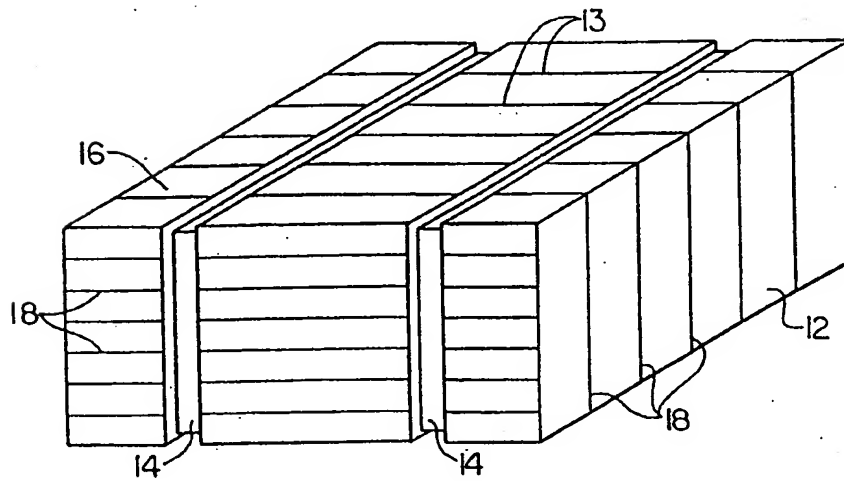


FIG. 10

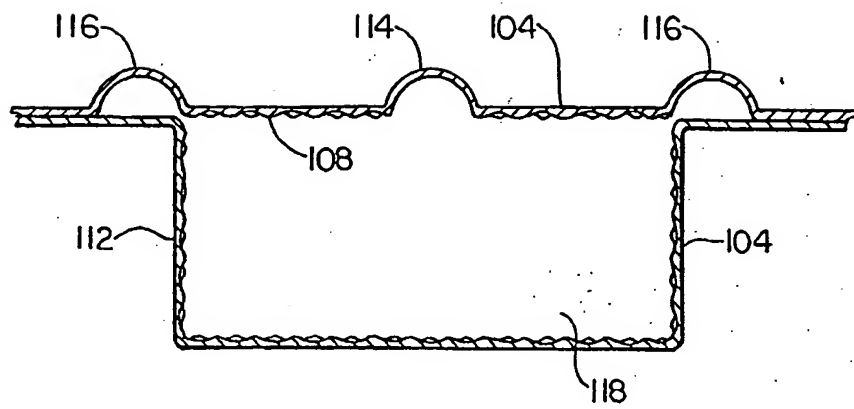


FIG. 11

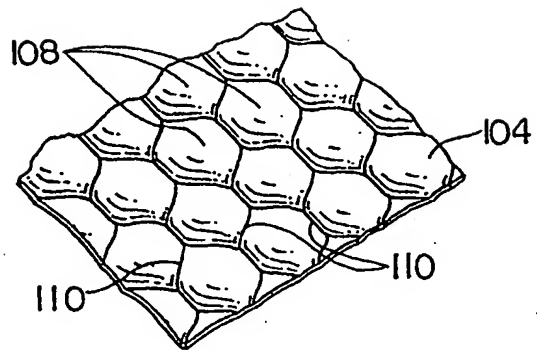


FIG. 13

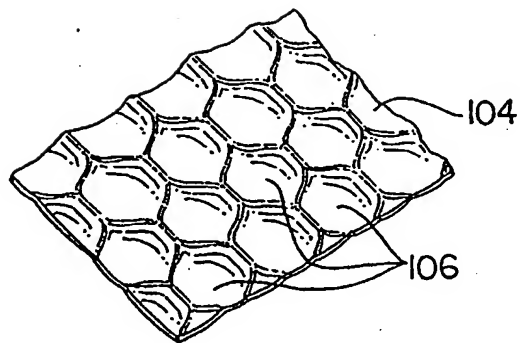


FIG. 12



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 03 07 5169

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	US 5 304 339 A (LE COMTE ADOLF) 19 April 1994 (1994-04-19) * column 9, line 35 - column 11, line 3; claim 1; figures 5,6 *	1-14	B29C70/36 B29C70/44 B29C43/02 B29C43/36
X	US 4 902 215 A (SEEMANN III WILLIAM H) 20 February 1990 (1990-02-20) * claim 1; figures 3-7,9 *	1	
A	US 5 132 069 A (NEWTON JOHN R) 21 July 1992 (1992-07-21) * claim 1; figure 2 *	1-14	
			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
			B29C
The present search report has been drawn up for all claims			
Place of search MUNICH		Date of completion of the search 28 February 2003	Examiner Dupuis, J-L
CATEGORY OF CITED DOCUMENTS		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons A : technological background O : non-written disclosure P : intermediate document	
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		I : member of the same patent family, corresponding document	

EPO FORM 1503 (03.02) (P/C/D1)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 03 07 5169

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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28-02-2003.

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82